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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : G01N 21/88 | A1

(11) International Publication Number: WO 87/00629

(43) International Publication Date: 29 January 1987 (29.01.87)

(21) International Application Number: PCT/GB86/00399

(22) International Filing Date: 11 July 1986 (11.07.86)

(31) Priority Application Number: 8517834

(32) Priority Date: 15 July 1985 (15.07.85)

(33) Priority Country: GB

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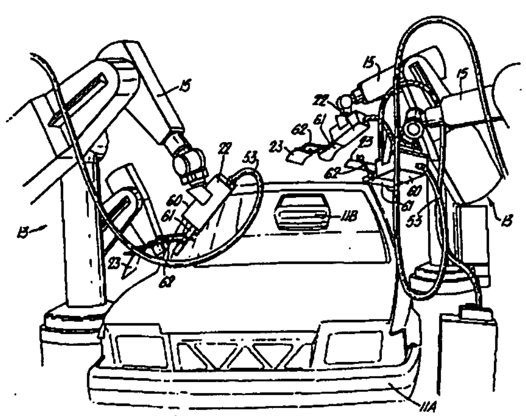
(81) Designated States: AT (European patent), BE (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, NL (European patent), SE (European patent), US.

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: INSPECTION APPARATUS



(57) Abstract

A surface inspection apparatus for inspecting a complex shaped surface, such as the paint surface of a motor car, comprising laser means (31) providing a beam (26) of radiation, scanning means (39) for scanning the beam across the surface, retroreflective material being provided to reflect radiation reflected from the surface back along the incident beam path, the apparatus including the retroreflective material being mounted as a unit to be moved over the surface of the motor car by means of a robot (13). Analysis of the light signal will indicate defects such as scratches, paint inclusions, orange peel, dry spray, dents and gloss defects and can distinguish the defects from features which should be present on the surface such as door cracks.

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INSPECTION APPARATUS

The present invention relates to an inspection apparatus which may be particularly useful in inspecting surfaces. However different aspects of the invention will have application in other fields, for example artificial vision systems and robotic control.

Thus although certain aspects of the apparatus will have applications elsewhere the inspection apparatus according to the invention will be described with reference to a particular apparatus which has been designed for use in inspecting surfaces, for example, painted or coated surfaces, and is particularly useful in examining complex shaped surfaces such as the painted surfaces of motor cars, domestic appliances and the like.

Automatically inspecting complex painted surfaces, for example, on a motor car production line, is extremely difficult and as a result the inspection has hitherto been carried out by human inspectors. Apart from the costs involved, the conditions under which inspectors work is often unpleasant both as to the environment and as to the tedious nature of the job. Furthermore although the human eye is very good at detecting defects, in practice it is not easy to arrange for reliable and consistent classification of defects.

Laser scanning arrangements have been known for scanning, for example, flat metal strip but have not hitherto been applicable to complex (ie three

dimensional) shaped surfaces. Thus for example in an arrangement in which a laser beam is passed to a flat surface it is simple to predict where the reflected beam will be and to collect the reflected beam suitably. In the case of a complex shaped object, however, it is difficult or impossible to predict the path of the reflected beam.

The present invention therefore provides, according to a surface inspection apparatus for a complex shaped surface comprising means for producing a beam of radiation, means for directing the beam at the surface means for scanning the beam across the surface a sheet of retroreflective material, means for moving the sheet of retroreflective material so as to maintain the retroreflective material adjacent to the position at which the beam of radiation strikes the surface whereby, in use, the reflected beam of radiation is intercepted by the retroreflective material and is reflected back along its original beam path, and means for receiving the beam of radiation reflected back along its original beam path.

Therefore the invention provides according to another aspect a surface inspection system for a complex shaped surface in which the beam of radiation is directed to the surface and scanned across the surface and a sheet of retro-reflective material is passed across the surface adjacent the position at which the beam of radiation strikes the surface.

Providing the retro-reflective surface close to the position at which the incident beam meets the surface the area of retro-reflective material required is reduced.

However, to scan the whole surface it is necessary to move the retro-reflective material and conveniently the radiation beam scanning means across the surface adjacent to the surface and this is conveniently done by means of a robot which is preferably pre-programmed to follow the contours of the complex shaped surface.

Another difficulty in dealing with complex shaped objects is that they tend to have complex shaped edges, corners and other features such as mouldings or creases which may produce signals which are similar to that of a defect. Thus means should be provided to analyse the signal from the defect detecting apparatus so as to distinguish between real defects, such as surface defects (eg paint defects, scratches, dents), and features of the surface. By "features" we mean mouldings, creases, edges, corners, holes and like features which are intended to be present in the complex shaped surface.

The present invention provides a surface inspection apparatus for inspecting a complex shaped surface comprising means for producing a beam of radiation, means for directing the beam of radiation at the surface means for scanning the beam across the surface, means for receiving the beam of radiation reflected

back from the surace, and means for analysing an output signal from the beam receiving means, the analysing means including means to distinguish between real defects and apparent defects which comprise features of the surface.

Clearly a problem also arises where the feature is, for example, a hole and a defect which is of the same shape. To distinguish between defects and features in this way the area, overall dimensions, and position of the defect is noted and from an analysis of these it is possible to distinguish between a defect and a feature.

We prefer to use a robot to move the scanning head across the surface but there are difficulties in the use of a robot. Most simple robots move directly between two points at a non-constant speed; because of the inertia of the robot it takes some time to speed up from the start point and it is decelerated towards the finishing point.

As a result of tests a memory of the velocity pattern of the robot is built up and utilised to determine the position of the scanning head at any particular time.

Through this specification we will refer to radiation, light, beam, and such references should be taken to include infra-red and ultra-violet wavelengths as well as optical wavelengths.

An inspection apparatus for inspecting complex shaped surfaces will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 is a plan view of a paint inspection station for a motor car assembly line incorporating the invention,

Figure 2 is a perspective view of the paint inspection station 10 taken from the downstream end of the track,

Figures 3 to 7 show the basic optical principle of light collection using a retro-reflective screen in conjunction with a laser scanner in the apparatus of Figures 1 and 2,
Figure 8 shows the layout of a scanning head in plan,

Figure 9 shows an elevation of the scanning head,

Figures 10 and 11 show two alternative arrangements of collection optics including a photomultiplier,

Figure 12 shows a general arrangement of the electronic processing of the signals from the scanning head,

Figure 13 is a diagram of the electrical and electronic

circuit components associated with the scanning head,

Figure 14 shows a signal summation and subtraction circuit,

Figure 15 shows a discrete defect detector circuit,

Figures 16 to 24 illustrate signals,

Figure 25 shows a position tracking and discrete defect interface,

Figure 26 shows the area of a car panel which is viewed by a single swathe including a feature and a number of defects,

Figure 27 shows a different area of a different panel viewed by a different swathe,

Figures 28 and 29 show other areas of other panels viewed by different swathes,
Figure 30 shows a typical signal produced by orange peel,

Figure 31 shows a typical signal produced by dry spray,

Figure 32 shows a orange peel and dry spray detection circuit,

Figure 33 shows signals from which the gloss may be determined,

Figure 34 shows in diagrammatic form a gloss defect detector circuit,

Figure 35 shows in diagrammatic form a dent detector circuit, and,

Figure 36 shows a large area defect interface,

GENERAL ARRANGEMENT OF APPARATUS

Figure 1 is a plan view of a paint inspection station for an assembly line which in the preferred embodiment is a motor car assembly line. The motor cars 11 proceed successively through the paint inspection station 10 from right to left in Figure 1 along a track 12. Within the paint inspection station there are mounted six robots 13A to 13F spaced in two lines of three on each side of the track 12 at suitable intervals. A car identifying sensor 14 identifies each car from its shape as it enters the paint inspection station 10. The car identifying sensor 14 will identify which model the motor car is, and whether it be saloon, estate car, van and so on.

Although the motor cars 11 are quite closely aligned with respect to the track 12 there is some slight misalignment and this is measured by means of car alignment measurement means 16. This measures the alignment of the car widthwise with respect to the track 12 and takes into account, for example, any skew of the car alignment with respect to the track 12.

In front of each robot 13 is mounted a trigger 17 which informs its associated robot as to the position of the front edge of the car 11. Adjacent the paint inspection system 10 there is mounted a console 18 for use by an operator of the paint inspection station 10, the console being attached to a printer 19 and a visual display unit (VDU) 21.

Each robot 13 carries at the end of its arm 15 a scanning head 22 which incorporates a retro-reflective plate 23, the scanning heads 22 being passed over the surface of the motor cars (six being provided to cover the complete outer surface). Each sweep of the arm 15 of each robot 13 moves the scanning head 22 over the surface of the motor car in one direction and the area which the scanning head views during this single sweep of the arm 15 is referred to as a swathe. The swathes are generally arranged so as to be parallel to one another and side by side so as to view the complete surface of the motor car with the minimum movement and overlap.

As will be described later, a laser beam is scanned over the surface of the motor car during inspection and this scanning is carried out by means of lines which are at right angles to the direction of swathe. Thus the robot arm moves the scanning head in a first direction along the scathe and the scanning head scans the laser beam across the surface whereby the surface is inspected by the laser beam (the directions are indicated in Figure 26 supra).

Figure 2 is a perspective view of the paint inspection station 10 taken from the downstream end of the track 12 showing a motor car 11 being inspected by the robots 13.

THE OPTICS OF DEFECT DETECTION

Figures 3 to 7 show the basic optical principle of light collection using a retro-reflective screen in conjunction with a laser scanner.

Figure 3 shows the effect of the reflection of a laser beam off a normal flat specular surface where the reflected beam 26 after striking the retro-reflective screen 23 returns in the incident direction but with a slight divergence to be re-reflected at the specular surface 27 back in the original incident direction. Figures 4 and 5 show the effects on the laser beam 24 when the specular surface 27 is displaced and tilted respectively. The return laser beam 24 again returns exactly along the incident direction. Similar effects are produced if a uniform optical or cylindrical surface are encountered.

If a defect which absorbs light is encountered by the incident laser beam 24 then of course the returned light will be attenuated. Also if a scratch or dirt is encountered then some or all of the light will be scattered away from the retro-reflective screen 23 and therefore not returned, which will again attenuate the returned beam. Small dents will produce similar signals, as can be seen in Figure 6 when the returned

diverged beam from the screen 23 surrounding the incident laser beam 24 will be deviated at a different angle from the original incident direction and will therefore not be collected.

Large area dents will not in general deflect the returning light away from the collection direction, but will deviate the light in a non-uniform manner as shown in Figure 7. Thus by analysing the distribution of the light in the collected beam such dents are distinguishable from normal surface curvature.

SCANNING HEAD

The layout of the scanning head 22 is shown in plan in Figure 8 and in elevation in Fig. 9. A laser 31 is mounted under a central plate 32 to help reduce the size of the head 22. The beam 24 is brought through the plate 22 by means of two right angled prisms 33, 34. Three lenses 36 to 38 on an optical track then shape the beam 24 and ultimately focus the beam 24 on to the inspected surface 27 in the form of a spot, which can be adjusted to be any size between 0.5 and 1.5 mm and 0.5 mm wide (in the scanning direction). The beam 24 is scanned by means of a 12 sided polygon scanner mirror 39 which is rotated by motor 41 at 10,000 rpm to give 2000 scans per second. The active part of the scan is determined by the acceptance angle of a collection lens 42 ie 35 $^{\circ}$. The beam 24 is reflected by a strip mirror 35 to an aspheric acrylic lens 43 to collimate the dynamic scanned laser beam 24 so that the scan length is constant at any distance

from the car body, (it also allows a smaller retor-reflective screen to be used compared with a diverging scan).

The laser beam 26 specularly reflected from the car body strikes the retro-reflective screen 23 as described above and returns back in the incident direction to be re-reflected at the car body back to scanning head 22. The collimating lens 43 then redirects the beam 26 back towards the scan origin at the polygon mirror 39. However as the beam 26 is now slightly diverging a large part of the beam 26 is separated from the main beam by the strip mirror 35. The light which passes the mirror 35 is collected by the collection lens 42 at the same distance from the mirror 39 as the relevant facet of the mirror 39 is from the mirror on the other side. The lens 42 is arranged to form a focus of the scan line on the retro-reflective screen 23 onto a pair of narrow light guides 46, 47. A small prism 48 is positioned within the lens 42 so that light passing through the central aperture is divided into two spatially separated parts one being focused onto one light guide 46 and the other onto the other light guide 47. At the back of each light guide 46, 47 a linear array of optical fibres 51, 52 is used to collect the light for transmission to a remote detector unit 56, 57.

There is also provided an optical fibre 44 the end of which is disposed alongside mirror 35 in such a position as to detect the start of scan of the laser beam across the mirror 35 and hence the start of the

scan. There is also provided an optic fibre 49 which continuously receives light from the laser 31 so as to detect whether the laser is on. Lastly, there is a gloss fibre 50.

The linear arrays of fibres 51, 52 are loosely bunched for containment within a flexible protective cable 53 between the head 22 and the detector sited at the base of the respective robot 13. Within the cable 53 the fibres are recombined into two separate ferrules where the fibres are arranged in a circular format. The ferrules are sited in front of respective photomultiplier detectors 56, 57 as shown in Figure 10. A gelatin red filter 54 is used to transmit only red light which reduces the level of ambient light detected by the detector 56, 57. If the level of ambient light is very high then a lens 38 and an interference filter 59 with a narrow wavelength bandpass is used instead as shown in Figure 11.

Referring back to Figure 2 the physical shape of the scanning head 22 is clear from that Figure, the apparatus being enclosed within a rectangular box 60, with a fan shaped hood 61 through which the scanned beam passes (the hood 61 being provided to reduce the ambient light passing through to the scanning head optics), and the retro-reflective screen 23 is adjustably mounted on two arms 62.

GENERAL ARRANGEMENT OF ELECTRONIC PROCESSING

Figure 12 shows a general arrangement of the circuit

for electronic processing of the signals from the scanning head 22. Thus in general, signals from the detectors 56, 57 are passed to a signal summation and subtraction circuit 66 and an output which is derived from the sum of the signals from detectors 56, 57 is passed to the summed line 67 and a signal which is derived from a subtraction of the signals from detectors 56, 57 is outputted from circuit 66 along line 68.

Four circuits are provided to detect different types of defects as follows, discrete defect detector circuit 70 gloss defect detector circuit 71, orange peel and dry spray detector circuit 72, and dent detector circuit 73. The summed signal line 67 is connected to the discrete defect detector circuit 70 and gloss defect detector circuit 71 and the subtracted signal line 68 is connected to the orange peel and dry spray detector circuit 72 and to the dent detector circuit 73. It will be understood that the summed signal is used in the discrete defect detector circuit (and the gloss defect detector circuit) because the maximum signal value is required.

The means of operation of these various circuits 70 to 73 will be described later but they each provide outputs: in the case of discrete defect circuit 70 an output on line 74 to a position tracking and discrete defect interface 76: the output of the gloss defect detector circuit 71 is passed along lines 77 to a local processor 78: the output of the orange peel and dry spray detector circuit is passed along lines 79 to a

large area defect interface 81 as is the output on line 82 from the dent detector circuit 73. Each of the circuits 71, 72, 73 is also connected to the position tracking and discrete defect interface 76 by means of lines 84, 85, 86 along which positional information is passed.

The output of the position tracking and discrete defect interface 76 is passed along line 87 to the local processor 78 and the outputs from the large area defect interface 81 are also passed along lines 88 and 89 to the local processor 78. The local processor 78 also receives along line 80 information from its respective robot 13. The combination circuit 92 (which is within a computer and is both hardware and software) controls the printer 19 and the system supervisor circuit 93 controls the VDU 21.

A central processor 91 (which is also a combination of hardware and software) is provided to receive signals from each of the six local processors 78 which receive signals from respective scanning heads 22. The central processor 91 includes a combination circuit 92 for combining the data from the six systems and a system supervisor circuit and data store 93 which stores data from the combination circuit 92 and which supervises the overall system. The circuit 93 includes an input from the car identifying sensor 14.

SCANNING HEAD ELECTRONICS

Figure 13 is a diagram of the electrical and electronic

circuit components associated with the scanning head 22 and may be read in particular in conjunction with Figures 8 and 9.

As is clear from Figure 13 the two detectors 56, 57 are mounted in a receiver box 96 and the laser on fibre 49 and start of scan fibre 44 are also connected to a safety interface and driver circuit 97, outputs from which pass along line 98 to a laser power supply unit 100 within the motor drive circuit 41 to act as a safety cut-out and also to line 99 to provide a start of scan signal. Figure 14 shows the signal summation and subtraction circuit 66. Input signals on lines 63 and 64 are fed to two amplifiers, a summing amplifier 101 and a subtracting amplifier 102.

DISCRETE DEFECT DETECTOR CIRCUIT

The discrete defect detector circuit 70 will now be described in more detail with reference to Figure 15. The summed video signal is inputted on line 67 (the input signal on line 67 being illustrated in Figure 17), Figures 16 to 24 illustrate the signals for a single scan.

The input signal on line 67 is passed through a first filter 103 which removes the noise and produces a filtered signal illustrated in Figure 18. The filtered signal is passed to a first input of a comparator amplifier 108. The filtered signal is also passed to a second filter 109 which further removes noise and provides a reference signal illustrated in Figure 19 in

hich the effect of the defect is reduced indicated at 105. The reference signal is passed through a proportional amplifier 111, the output of which provides a signal which is approximately 90% in amplitude of the value of the reference signal and is illustrated in Figure 20. This 90% of the reference signal is applied to the second input of the comparator 108 which subtracts the signal of Figure 20 from the signal of Figure 18. Thus the comparator 108 is arranged so as to provide a "true" logic signal on output line 110 if the 90% of the reference signal (Figure 20) is greater than the filtered signal (Figure 18) (and a different "untrue" logic signal if the reference signal is less than the filtered signal). This will only occur where there is a defect, in other words it will only occur at the point 105 and before and after the signal and so a logic output signal (illustrated in Figure 22) is provided on line 110. This logic output signal is applied to one input of a gate 112.

The filtered signal from filter 103 is also passed to a control signal generator 106 along line 104. Within the generator 106 there is provided a comparator 107 which sets a threshold level against the filtered signal to produce, in combination with circuit 113, a logic "true" signal on line 114 corresponding to the length of the signal for a single scan (illustrated in Figure 23). This output is applied to the other input of the gate 112. Gate 112 is arranged so as to pass the "true" logic signal from line 110 only when the gate signal on line 114 is "true" and the effect of

this therefore is to provide an output on line 74 which corresponds only to the part of the logic signal (Fig. 22) produced by the defect. There is therefore provided, as is clear from Figure 24, an output which incorporates a "true" logic pulse only when there is a defect signal 105.

POSITION TRACKING OF ROBOT

One of the problems is that discrete defects clearly only occur at specific points across the surface and it is important to know exactly where these discrete defects occur. Other defects such as gloss, orange peel and dents are larger defects and their exact position is not so important.

Thus, with the signal produced on line 74 indicating discrete defects it is necessary to know the position of the defect and this is complicated by the fact that the robot moving the scanning head 22 does not move at a continuous rate but because of inertia takes some time to speed up and some time to slow down. A further difficulty is that there are certain features of the surface, for example creases, edges and the like, which will appear as discrete defects and will be picked up by the discrete defect detector circuit. These must clearly be eliminated. Both these functions are carried out by the position tracking and discrete defect interface 76 which will now be described in greater detail with reference to Figures 25 and 26.

The interface 76 includes a memory 121 which

incorporates within it the swathe profile. Effectively this takes into account the fact that over the first millimetre of movement of the robot arm there will be, say 20 scans per millimetre whereas in the middle of its movement between the two ends of the swathe there will be as few as two scans per millimetre of movement. The memory 121 operates so that only, for example, one of the first twenty scans are considered, rejecting the other nineteen, two in the next twenty scans, four in the next twenty scans, up to a position in which all of the scan lines may be considered. In this way the surface is examined by the circuitry from beginning to end of the swathe in a more even manner.

The swathe profile memory 121 contains a series of numbers, for example 20, 8, 5, 2 ..., 9, 25 which relate to the number of scans produced per millimetre through the swathe because of the slow start of and slow finishing of movement of the robot. At the start of the scan, the memory 121 downloads the first number into a first counter 123. As can be seen the counter 123 includes a start of scan signal from line 99. Thus, initially, the counter 123 is loaded with the number 20 and it counts downwards towards zero each time a start of scan signal is passed from line 99. When it reaches zero it passes a signal to a second countere 125. Simultaneously it passes the signal on line 122 back to the memory 121 which thereby loads the second number (in this case eight) into the counter and the sequence is repeated.

Thus by operation of the memory 121 and the counters

123 and 125 an output is produced on lines 127 which indicate the number of millimetres through a particular swathe which the scanning head 22 is examining.

Line 99 is also connected to the input of a counter 128 so that the counter 128 receives a succession of start of scan signals, the counter 128 also being connected to a clock 129. The clock 129, counter 128 and a ROM encoder 131 to which the output of the counter 128 is connected, operate utilising the start of scan signal and the clock signal to provide an output signal from encoder 131 which indicates the number of millimetres through a particular scan, in other words millimetres across the swathe at any one point in time, this signal being passed onto line 132.

Thus a combination of signals on lines 132 and 127 (ie mms through scan and mms along swathe respectively) enable one to determine exactly the point which the scanning head 22 is examining at any one time. Both lines 127 and 132 are connected to interface logic circuit 133.

It will also be noted that the defect signal is passed along line 74 to a gate 134, the gate 134 receiving a signal from the counter 123 to indicate that a valid scan is taking place before the defect signal is passed to line 136 and hence to the interface logic circuit 133.

SWATHE MASKS

There is also provided a mask memory 137. The purpose of this will be explained in detail also with reference to Figure 26 which shows in diagrammatic form a portion of the surface which is examined during one swathe. The beam is scanned from left to right successively starting at the top and proceeding down towards the bottom of the rectangular area. The number of millimetres through the swathe is indicated on the left hand side starting at zero at the top and reaching 750 at the bottom and the number of millimetres across the swathe, in other words the number of millimetres along the scan is illustrated at the top of the diagram being zero in the top left hand corner and 200 in the top right hand corner.

Within the area of the panel being examined during this swathe there is a feature 138 which may be a door crack or a moulding or crease which is intended to be present in the panel under examination. Let us consider for the moment the scan numbered 139 which is at 120 mm from the beginning of the swathe. As the beam scans along the line 139 it reaches the feature 138 and will thereby produce a signal which the discrete defect detector circuit 70 will consider to be a discrete defect. However, it is not a discrete defect as the feature is meant to be present and thus it is necessary to provide some kind of memory which indicates to the apparatus that that particular signal relates to a feature rather than to a discrete defect. A further problem of course is that the motor car may not be exactly accurately aligned on the track 12 and so the position of the feature 138 may vary with respect to

the swathe. Thus there is provided in the memory 137 a mask which effectively indicates the maximum of the feature.

Referring to Figure 26, there is provided a masked area (area type 1) which extends from 0 to 200mm through the swathe, indicated by line 141 and from 0mm to 200 mm across the scan (indicated by line 142). A second masked area (area type 2) extends from 200 to 750 mm through the swathe and from 140 to 200 mm across the swathe. A third masked area (area type 3) extends from 450 to 560 mm through the swathe and from 22 to 66 mm across the swathe. The remainder of the swathe is referred to as area type 0. If a defect is indicated in area types 1, 2 or 3 then it must be examined further to make sure that it is a genuine defect and not a feature. Considering scan line 144, if a defect is indicated between 0 and 140 mm across the scan then it is clearly a genuine defect whereas if a defect is indicated between 140 and 200 mm into the scan then it may be the feature 138.

On the other hand, if the defect is in area type '0' then it can be considered a genuine defect.

To see how the system operates further we have introduced a number of defects 146,147,148 positioned as shown in Figure 26.

DEFECT SIGNALS THROUGH SWATHE

mm Through Swathe	X Scan Start	X Start Finish	Area Type	Note
99	0	174	1	Door crack 138
100	0	174	1	" " "
101	170	174	1	" " "
102	170	174	1	" " "
To	Ditto			
149	170	174	1	" " "
150	75	77	1	Defect 146
151	170	174	1	Door crack 138
152	170	174	1	" " "
To	Ditto			
199	170	174	1	" " "
200	170	174	2	" " "
201	170	174	2	" " "
To	Ditto			
349	150	155	2	Defect 147
349	170	174	2	Door crack 138
350	150	155	2	Defect 147
350	170	174	2	Door crack 138
351	150	155	2	Defect 147
351	170	174	2	Door crack 138
To	Ditto			
498	40	46	3	Hole 143
498	170	174	2	Door crack 138
499	39	48	3	Hole 143
499	170	174	2	Door crack 138
500	41	45	3	Hole 143

500	170	174	2	Door crack 138
To		Ditto		
650	24	26	0	Defect 148
650	170	174	2	Door crack 138
To		Ditto		
750	170	174	2	" " "

Although only one defect in the above example is provided in the area'O' in practice most defects will be in that area and the effect of distinguishing between different areas in this way is to reduce the amount of computing power that is necessary since if the defect is in the area 'O' less further computation is required whereas if the defect appears to be in the Area 1, 2 or 3 further calculations are necessary.

Referring back now to Figure 25 the memory 137 includes, for each swathe, a map designating the Areas 0, 1, 2,3. An area number generator 151 communicates with the memory 137 and with the counter 123 and encoder 131 so as to provide an output on lines 152 indicating at all times whether the beam is in an Area 0, 1, 2 or 3 by comparing the inputs from lines 127 and 132 with the information in the memory 137. The output 152 is fed to the interface logic circuit 133. Interface logic circuit 133 has a plurality of outputs including the area information (output 153), the mm through swathe information corresponding to input 127 (output 154), the mm across swathe and the cross scan start number value on lines 155 and a cross scan finish number value on lines 156 and a defect signal inputted

from line 136 is passed out on line 157. This information is inputted to a FIFO buffer 158 (that is a first in first out buffer) where the information is buffered and then is passed to the local processor 78 by lines 87.

Both memories 121 and 137 are loaded by the local processor through lines 159, 161.

LOCAL PROCESSOR

The function of the local processor 78 at least so far as dealing with discrete defects will now be described. Its function with respect to other kinds of defect will be described later.

The local processor continuously compares the input information relating to the type of area which is being scanned at a particular time with the discrete defect information. If the discrete defect information occurs in an Area type 'O' then this information is passed onto the central processor 91 together with an indication derived from lines 127 and 132 as to the exact position of the defect. In practice it carries out a minor amount of signal processing even on these signals.

EXAMINATION OF DEFECT ADJACENT A FEATURE

If however the defect signal is received from an area 1,2 or 3 then the local processor carries out a considerable amount of processing of the signal

information before it is passed on to the central processor. The local processor determines whether the apparent defect signal is from a genuine defect or is from a feature.

The signal processing is generally carried out in software. Referring to Figure 27 in which there is a feature 162, for example a fold in the metal or a gap between the door and associated panel, it is known that the feature extends throughout the swathe from top to bottom and so, in software, each of the defects is looked at and if it can be added to an adjacent defect on an adjacent line then they are so joined together and the total length of the joined defects is then calculated. If that length is, for example, the same as the length of the swathe then clearly all of those joined up defects form the feature. If, however, the defect, although occurring in an area type 2, does not join up with an adjacent defect or if several adjacent defects do join up (for example if the defect is of reasonable proportions) then the length of the joined up defects is considered and clearly it will not equal the length of the feature and will thereby be detected and considered to be discrete defects and indicated as such.

A second type of feature is illustrated in Figure 28 and this could correspond to the feature 143 in Figure 26. Figure 28 is an enlargement of the area 3. The feature 143 comprises a bolt hole and for the purpose of this matter there are provided two discrete defects 163, 164 within the area 3. In this case all of the

defects are joined together as before and the software then calculates for each of the apparent defects the area of the defect and, perhaps, its maximum length in one particular direction. The area of the feature, the bolt hole, is known and so that area is compared with the area of the apparent defect and in the case of the apparent defect 143 will coincide approximately with the area of a bolt hole and will therefore be detected as the bolt hole, that is as a feature, but the area of the defects 163 and 164 will be below the threshold area for the bolthole and will therefore be indicated as proper defects.

Another type of feature is illustrated in Figure 29. In this case, the swathe includes the edge of a panel, for example the edge of the roof of a vehicle and so to the right of the swathe shown in Figure 29 the laser beam does not return because it has passed beyond the edge of the panel. In this case, the feature comprises a continuous line 167 and all signals to the right of that line 167 can be ignored. The line 167 must stretch from top to bottom of the swathe in this particular case and so any defects to the left of that particular line 167 which can be readily calculated will be genuine defects. It is necessary to ignore signals to the right of the line 167 because in some particular cases, particularly where the line 167 comprises the edge of a roof, there may be some reflection back from a lower part of the body, for example the wings, which would provide some kind of signal as at 166.

In this case, the area to the right of line 168 is an area type 2 but having established line 167 a defect such as 169 can be readily identified as a genuine discrete defect.

ORANGE PEEL AND DRY SPRAY DETECTOR CIRCUIT

We now return to consideration of the orange peel and dry spray detector circuit 72. With orange peel and dry spray which tends to produce a sort of roughness on the surface of the paintwork it is believed that the reflected laser beam is slightly deflected by the roughness and so the signal on one channel will increase while the signal on the other channel will decrease and vice veresa. Thus the orange peel and dry spray can be more readily identified by using the subtracted signal on line 68 and Figures 30 and 31 show respectively typical signals for orange peel (in the case of Figure 30) and dry spray (in the case of Figure 31).

The difference between the two types of signal is largely a matter of frequency.

The orange peel and dry spray detection circuit 72 is illustrated in more detail in Figure 32. The subtracted signal on input line 68 is passed to two band pass filters 171, 172 and band pass filter 171 is arranged so as to pass the frequency of signal which would correspond to the orange peel effect. Clearly the frequency range is set as a matter of practice. The output signal from band pass filter 171 is passed

to full wave rectifier 173 and the output signal from the rectifier 173 is passed to an integrator 174 which produces an output signal which is the sum of the input signal. In general terms, the value reached by the ramp during a time interval, for example one scan line, or a succession of scan lines, or an area formed of a succession of parts of scan lines as will be clear later, is a measure of the orange peel. Thus the threshold value can be set because some orange peel will be acceptable. A similar processing is carried out for dry spray effect by means of a full wave rectifier 176 and an integrator 177, the only difference being that the frequency of the band pass filter 172 is different so as to discriminate between orange peel and dry spray.

As mentioned above the area over which the signal is integrated by integrator 174 or 177 is a small proportion of the swathe, for example typically 50 x 64 mm and in practice orange peel and dry spray is only considered in area type O. If orange peel or dry spray are present then it will be present across wide areas and there is no need for the complication of taking into account features and the like as with the discrete defect signal processing. As a result, therefore, it is necessary for the orange peel and dry spray detector circuit 72 to receive information from the interface 76 as to the position of the scanning beam at any particular time so as to determine whether it is necessary to look for orange peel and dry spray or not and also in order to calculate the particular areas over which the signal must be integrated.

GLOSS DEFECT DETECTOR

In general terms the gloss is measured by measuring the level of reflected signal. Clearly the greater the level of reflected signal the greater the amount of gloss on the particular paintwork being examined. However it is necessary to provide some kind of reference to take into account variations in the intensity of the laser beam which may vary slightly with time. Referring back to Figures 8 and 9 there is provided a reference fibre 44 which receives the laser beam each time it is swept across the mirror 35 and this optical signal which is provided on line 50 of Figure 13 is used to provide the reference signal. As is clear from Figure 12 the gloss defect detector circuit 71 receives the summed signal on line 67 as well as the signal from the line 50. The signal is illustrated in Figure 33, a pulse 181 providing the reference pulse and signal 182 being the summed signal from line 67 for a single scan line. The bottom part of Figure 33 shows a further reference pulse 183 of unit height and optical width corresponding to signal 182. The reference pulse 183 is present only whilst the beam is scanning an area 'O'. Thus if all of the scan line within area 'O' then reference pulse 183 exists for the whole scan line, but if part of the scan line includes other areas then it will be less than the whole scan line.

The area below signal 182 is defined as a and the area below signal reference pulse 183 is defined as d. The

height of the reference pulse 181 is defined as h.

For the purposes of this apparatus the gloss is defined as a/hd.

Referring to Figure 34 which shows in diagrammatic form the gloss defect detector circuit 71 the signal input from line 67 which includes the reference pulse 181 is passed to circuit 184 which produces an analogue output signal on line 186 being a signal the value of which is related to h. This is passed to a multiplier circuit 187. The signal on line 67 is also passed to an integrator 188 which thereby produces a ramp output signal and the value of this integrated signal for a single scan is passed to a peak hold circuit 189. The peak hold circuit 189 holds the peak value for the previous scan.

The effective output of the peak hold circuit 189 is an analogue voltage on line 191 which is a function of the area a. Integrator 193 is provided with an input like signal 183 and similarly integrates that signal, the output of the integrator 193 being passed to a peak hold circuit 194 similar to peak hold circuit 189 and the output of that peak hold circuit 194 provides an analogue voltage which is proportional to d. This is passed to the multiplier circuit 187.

Line 85 also provides an indication when an area other than area type 'O' has been reached and this switches off both integrators 188, 193 so that during this time the gloss detector circuit is not in operation.

The multiplier 187 multiplies together the analogue signal proportional to h and the analogue signal proportional to d to provide an output signal also analogue which is proportional to h x d. This signal is applied to the divider 192 to provide an output on line 77 which provides an analogue signal of the form a/hd. This output is passed direct to the local processor 78 where it may be compared with a predetermined signal value to determine whether the gloss is acceptable or is rejected. In practice the values of a/hd are integrated over 64 scans before being compared with a preset value as the gloss will not change noticeably over a small area and iuf it did it would be detected as a discrete defect.

Dent Detector Circuit

We shall now describe the dent detector circuit 73 with particular reference to Figure 35 which shows a logic diagram of the detector 73. In a sense, orange peel and dents are similar but of different proportions and it will be seen that some of the components of the dent detector circuit 73 are similar to those of the orange peel detector circuit 72. Thus the subtracted signal is fed to the circuit on input line 68 and is passed to a band pass filter 201, the pass band of which is chosen by experience to remove high frequency variations (in other words to remove orange peel and dry gloss signals and noise signals) and the output of the band pass filter is passed to a full wave rectifier 202. In order to be able to operate with different

scanners it is necessary to remove, in the signature removal circuit 203, the signature of the particular scanner. The signature is for example, the optical defects in the scanner which provide variations in the output signal during scanning and otherwise be detected as defects in paint. The signal is generated by means of the signature signal generator 204 which is loaded from the local processor.

The corrected signal is passed to a threshold circuit 206 and a digital dent defect signal is produced therefrom. The output produced by the threshold level detector 206 is controlled by means of an area basis. In respect of each particular sub-area a particular threshold is set. The number of sub-areas within a predetermined area providing signals above this threshold is counted and if this number exceeds a second threshold number then a dent defect signal is produced by the threshold detector 206.

Large Area Defect Interface

As is clear from Figure 12 the outputs from the orange peel and dry spray detector circuit 72 and dent detector circuit 73 are passed along lines 79 and 82 to the large area defect interface 81. This is illustrated in more detail in Figure 36. It is intended that the signal values from the orange peel detector circuit and the dent detector circuit should be accumulated over rectangular areas of the swathe. For example 50 mm wide by 62.5 mm. Positional information is received by the interface from lines 90

and this is passed to means which may be in software 211 to generate areas of 50 mm by 62.5 mm. The inputs from lines 79 and 82 are individually summed for the areas generated by the means 211 in the block 212 and this information is passed to a FIFO buffer 213 and thence to the local processor along lines 88, 89.

Local Processor 78

We now turn to the remaining functions of the local processor 78. The memory of the local processor contains maps of the areas 0, 1, 2 and 3 (see Figure 26) and passes that information to the mask memory 137. It also contains information regarding the swathe profile and that information is passed from the local processor to the swathe profile memory 121.

The local processor communicates with the robot. The robot produces limited information but does produce a signal indicating the number of the particular swathe and also indicating when it is beginning the swathe and ending the swathe and these three signals are passed to the local processor.

As already indicated the local processor accepts defect information direct from the gloss defect detector circuit 71 and indirectly from the discrete defect detector 70, the orange peel and dry spray detector circuits 72 and a dent detector circuit 73. The local processor stores the relevant information and passes it to the central processor only when required to do so. The reason for this is clear from an examination of

Figure 1. At any one time different robots 13 (for example 13A and 13B) may be working on different motor cars and so all of the information has to be collected in the local processor and then passed to the central processor at a relevant time so that the central processor 91 can collate all the information with regard to one vehicle.

Although already mentioned above the local processor stores information regarding the areas 0, 1, 2 and 3 for all swathes, it also stores this information for a variety of car styles as a variety of different types of car may pass along the track in succession with one another.

Central processor 91

The central processor 91 receives information from each local processor 78 for each robot and collates all of this information. As a result, when all this information has been passed to the central processor it is able to produce, on a drawing of each particular motor car, an indication as to where the defects are situated and what type of defects they are, be they discrete defects, gloss defects, orange peel, dry spray or dents. This information can be stored in the central processor and then downloaded at the end of each work shift into a memory.

The central processor also stores all mask and swathe process data for each type of car and for each robot and down line loads this information to the local

processors 78 at the beginning of operation during power up.

The central processor 91 also drives via the system supervisor 93 a VDU which enables the operator to see the status of the system and allows the operator to change threshold levels and the like.

The central processor keeps track of the cars from the car identification system 14 and triggers the local processor 78 at the relevant time.

There has thus been described a useful and practical arrangement for the inspection of surfaces, such as the surfaces of a complex shaped object such as a motor car. The invention is not restricted to the details of the foregoing example.

CLAIMS

1. A surface inspection apparatus for a complex shaped surface comprising means (31) for producing a beam (26) of radiation, means (43) for directing the beam (26) at the surface (27), means (39) for scanning the beam across the surface (27), a sheet (23) of retroreflective material, means (13) for moving the sheet (23) of retroreflective material so as to maintain the retroreflective material (23) adjacent to the position at which the beam (26) of radiation strikes the surface whereby, in use, the reflected beam (26) of radiation is intercepted by the retroreflective material (23) and is reflected back along its original beam path, and means (46,47) for receiving the beam of radiation reflected back along its original beam path.

2. Apparatus as claimed in Claim 1 in which the means (13) for moving the retroreflective material comprises a robot (13).

3. Apparatus as claimed in Claim 2 in which the robot (13) is pre-programmed to follow the contours of the complex shaped surface.

4. Apparatus as claimed in any of Claims 1 to 3 in which the means (31) for producing the beam of radiation, the means (43) for directing the beam at the surface, the means (39) for scanning the beam across the surface, the sheet (23) of retroreflective material, and the means (46,47) to receive the reflected radiation are mounted together as a unit (22) so as to be moveable together.

5. Apparatus as claimed in Claim 2 and 4 in which the

robot (13) moves the unit (22).

6. Apparatus as claimed in Claim 4 or 5 in which the scanning means (39), in use, scans the beam (26) substantially linearly across the surface and the unit (22) is moved in a direction generally perpendicular to the line of scan.

7. Apparatus as claimed in any of Claims 2 to 6 in which memory means (121) is provided which includes a memory of the velocity pattern of the robot (13) to determine the position of the retroreflective material (23) or the unit (22) during movement.

8. Apparatus as claimed in any of Claims 1 to 7 in which the scanning means (39) comprises a mirror drum scanner (39).

9. Apparatus as claimed in any of Claims 1 to 8 in which the means (31) for producing a beam of radiation comprises a laser (31).

10. Apparatus as claimed in any of Claims 1 to 9 in which the means (43) for directing the beam at the surface comprises a collimating lens (43).

11. Apparatus as claimed in any of Claims 1 to 10 in which means (56-93) is provided to analyse an output signal from the beam receiving means (46,47), said analysing means including means (78) to distinguish between real defects and apparent defects which comprise features of the surface.

12. Apparatus as claimed in Claim 11 in which the means (78) to distinguish real defects and apparent

defects comprises means (70,73,76,78,81) to determine the linear extent or area or position of the apparent defect to determine whether said linear extent or area corresponds with a feature.

13. A surface inspection apparatus for inspecting a complex shaped surface comprising means (31) for producing a beam (26) of radiation, means (43) for directing the beam of radiation at the surface (27), means (39) for scanning the beam (26) across the surface (27), means (46,47) for receiving the beam (26) of radiation reflected back from the surface (27), and means for analysing an output signal from the beam receiving means, the analysing means including means (70,73,76,78) to distinguish between real defects and apparent defects which comprise features of the surface (27).

14. Apparatus as claimed in claim 13 in which the means (70,73,76,78) to distinguish real defects and apparent defects comprises means (76,78,81) to distinguish between defects which are continuous in space and defects which are not continuous in space.

15. Apparatus as claimed in Claim 13 or 14 in which the means (70,73,76,78) to distinguish real defects and apparent defects comprises means (76,78,81) to determine the linear extent of an apparent defect and means (78) to determine whether the said linear extent corresponds with the linear extent of a known feature.

16. Apparatus as claimed in any of Claims 13 to 15 in which the means (70,73,76,78) to distinguish real defects and apparent defects comprises means (78,81) to determine the area of an apparent defect and means (81)

to determine whether the said area corresponds with the area of a known feature.

17. Apparatus as claimed in any of Claims 13 to 16 in which the means (70,73,76,78) to distinguish real defects and apparent defects comprises means (76,78) to determine the position of an apparent defect and means (78) to determine whether the said position corresponds with the position of a known feature.

18. Apparatus as claimed in any of Claims 13 to 17 in which the output signal analysing means including means (66,72,73) to detect spatial movement of the reflected beam (26).

19. Apparatus as claimed in claim 18 in which the means to analyse the output signal includes means (72) to detect the frequency of spatial movement of the reflected beam (26) and thereby analyse the type of defect.

20. Apparatus as claimed in any of Claims 13 to 19 in which the output signal analysing means includes means to detect the intensity (44,70,71) or changes in the intensity of the reflected beam (26) and thereby analyse the type of defect.

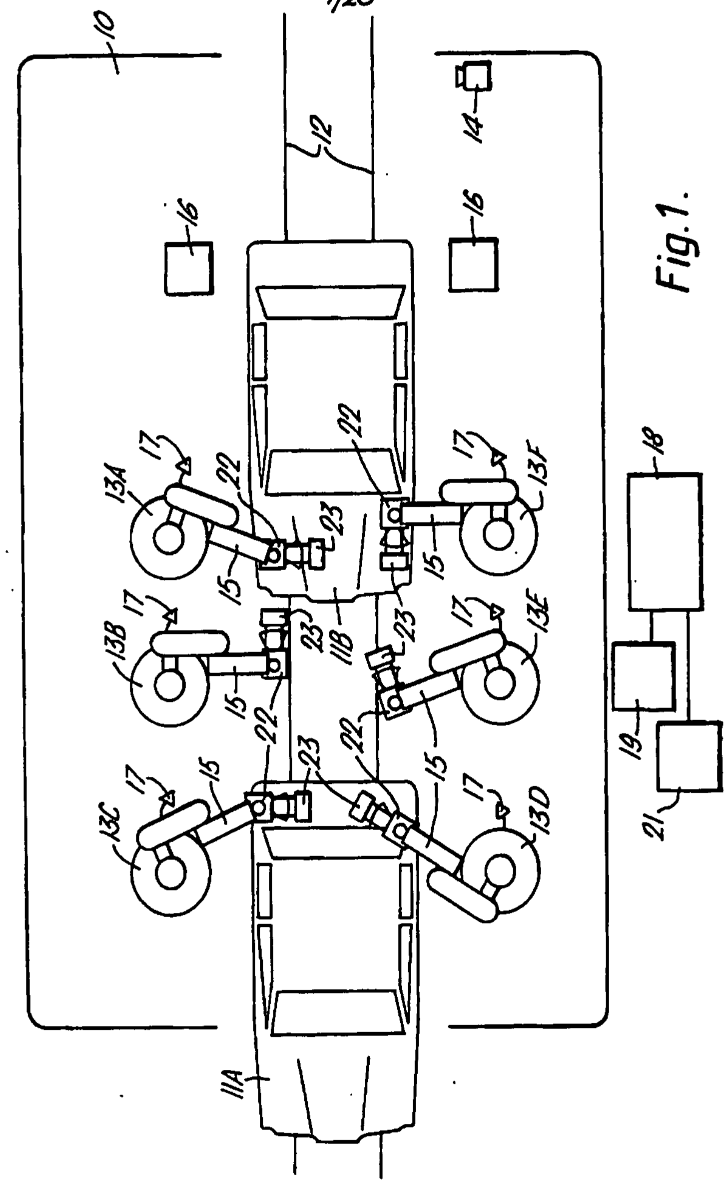


Fig.1.

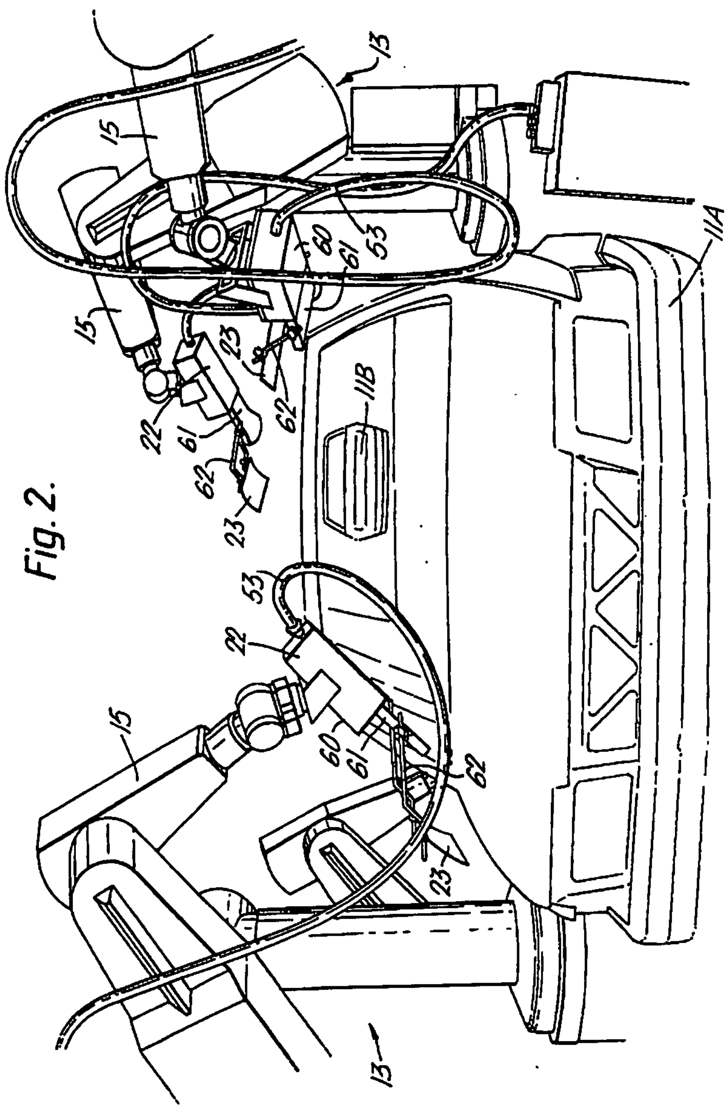


Fig. 2.

Fig.3.

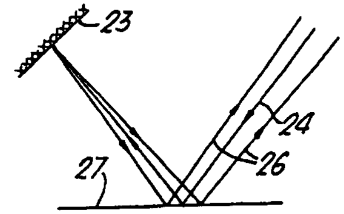


Fig.4.

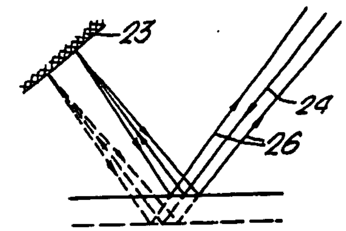


Fig.5.

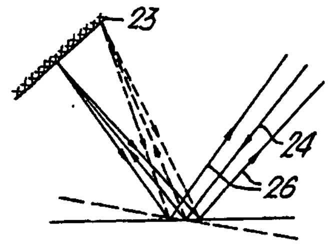


Fig.6.

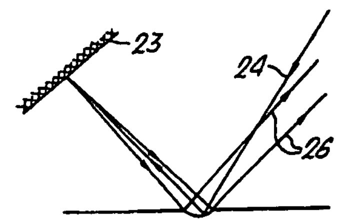


Fig.7.

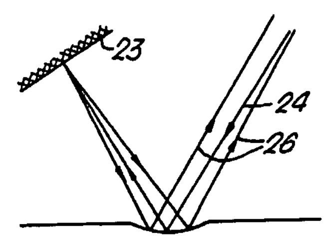
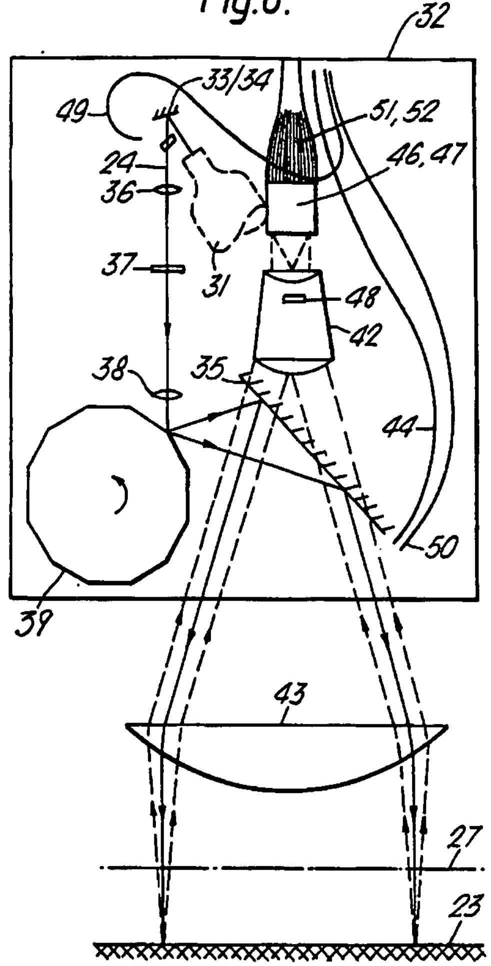


Fig.8.


32
33/34
49
51,52
46,47
24
36
37
31
48
42
38
35
44
50
39
43
27
23

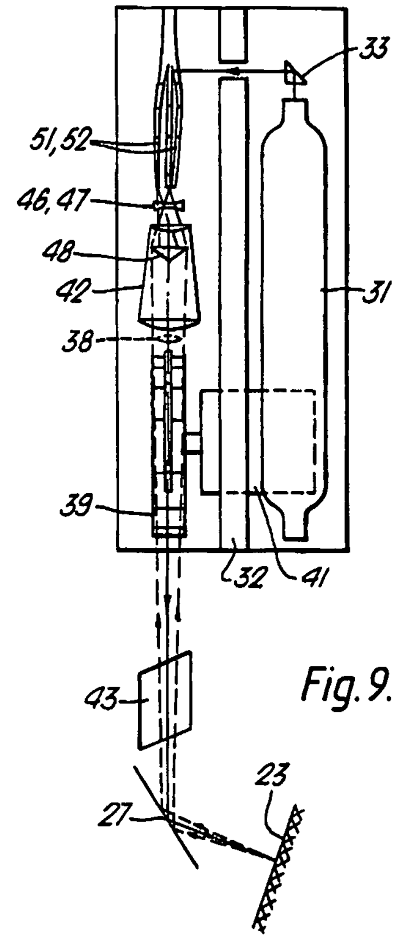

33
51,52
46,47
48
42
31
38
39
32
41
43
23
27

Fig.9.

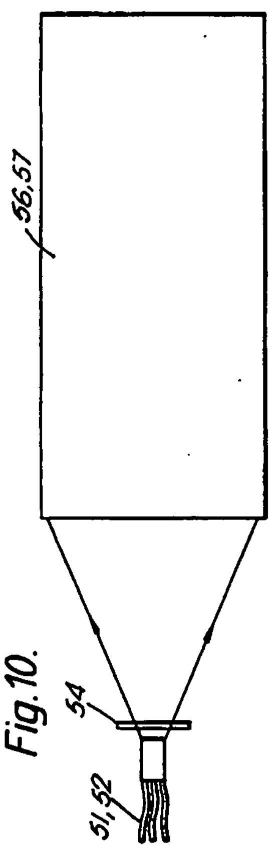


Fig.10.

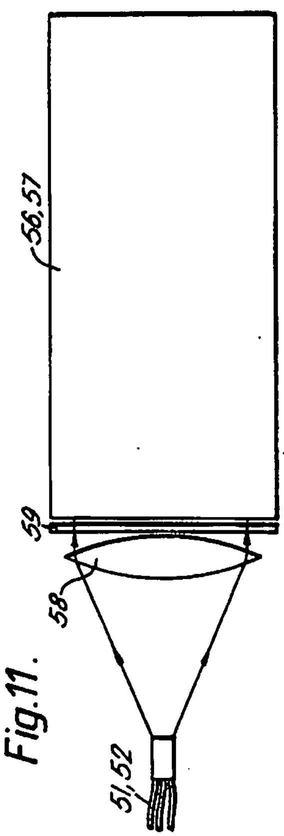


Fig.11.

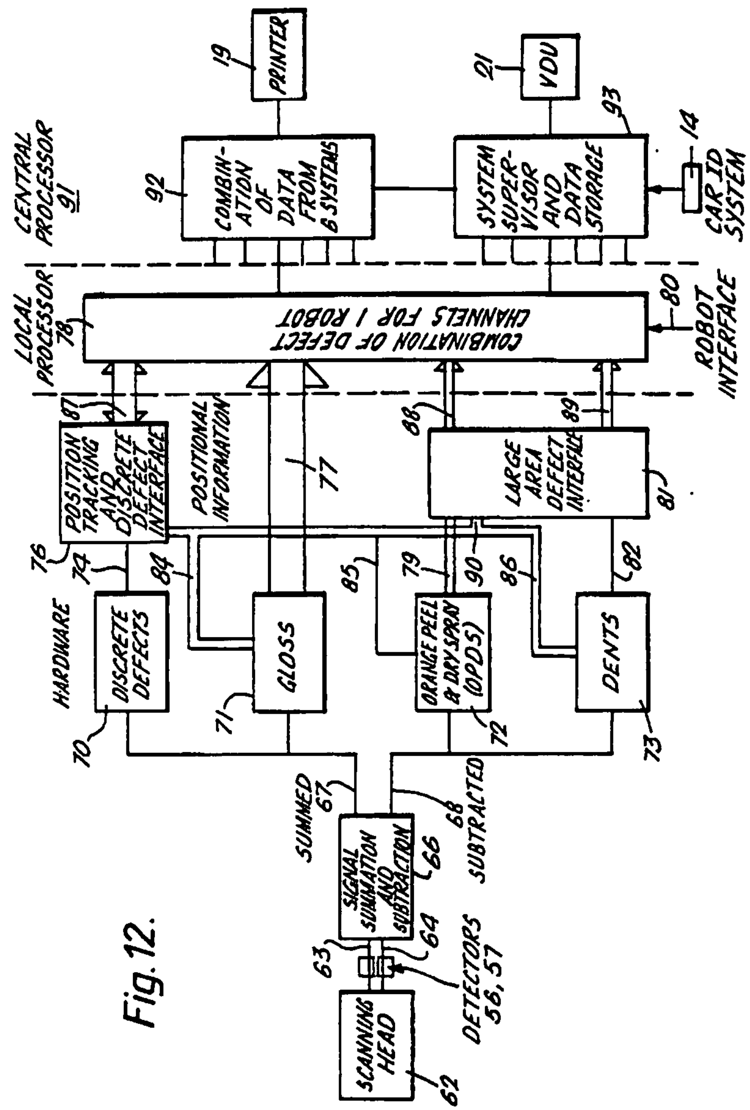
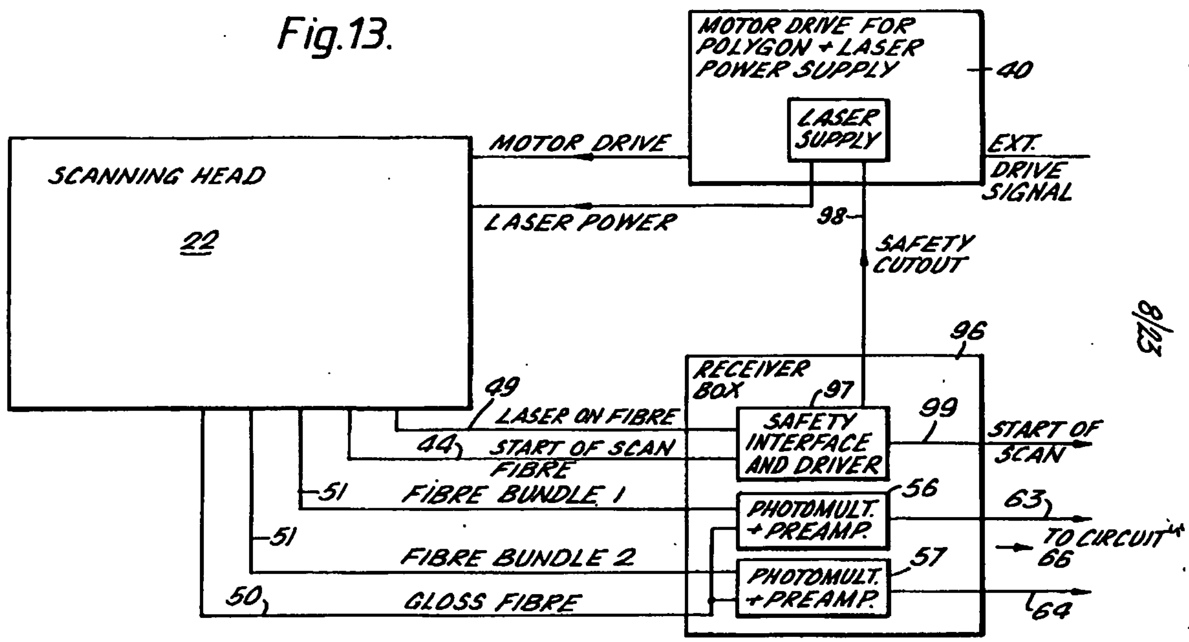


Fig.12.

Fig.13.


MOTOR DRIVE FOR
POLYGON + LASER
POWER SUPPLY
40
LASER
SUPPLY
EXT.
DRIVE
SIGNAL
MOTOR DRIVE
LASER POWER
SCANNING HEAD
22
98
SAFETY
CUTOUT
96
RECEIVER
BOX
97
SAFETY
INTERFACE
AND DRIVER
99
START OF
SCAN
49
LASER ON FIBRE
44
START OF SCAN
FIBRE
51
FIBRE BUNDLE 1
56
PHOTOMULT.
+PREAMP.
63
TO CIRCUIT
66
51
FIBRE BUNDLE 2
57
PHOTOMULT.
+PREAMP.
50
GLOSS FIBRE
64

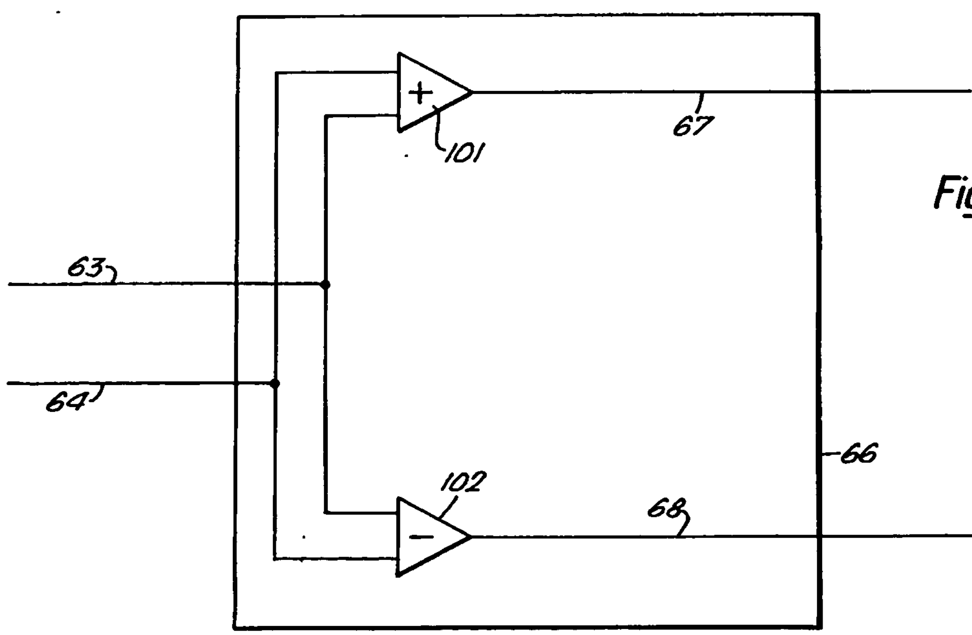

67
101
63
64
66
102
68

Fig.14.

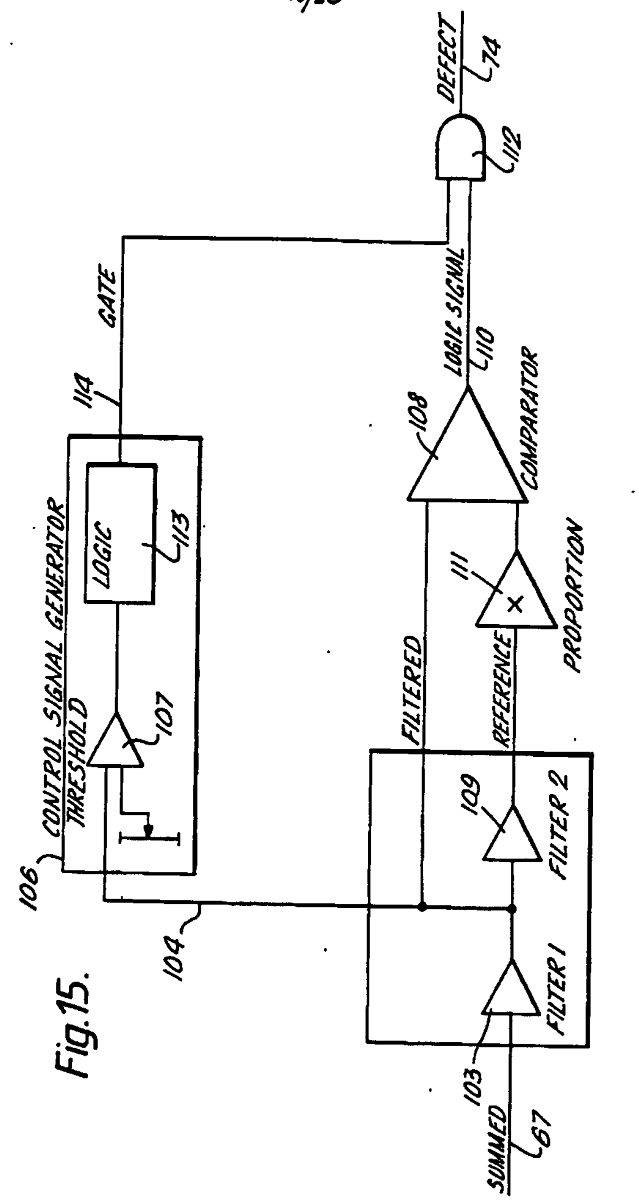


Fig.15.

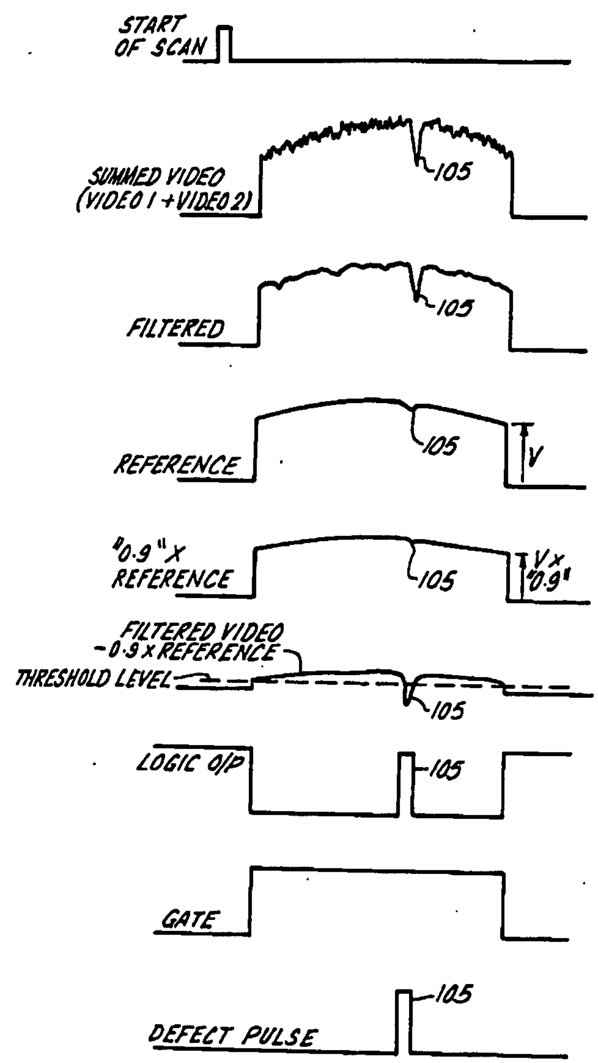


Fig.16. Fig.17. Fig.18. Fig.19. Fig.20. Fig.21. Fig.22. Fig.23. Fig.24.

12/23

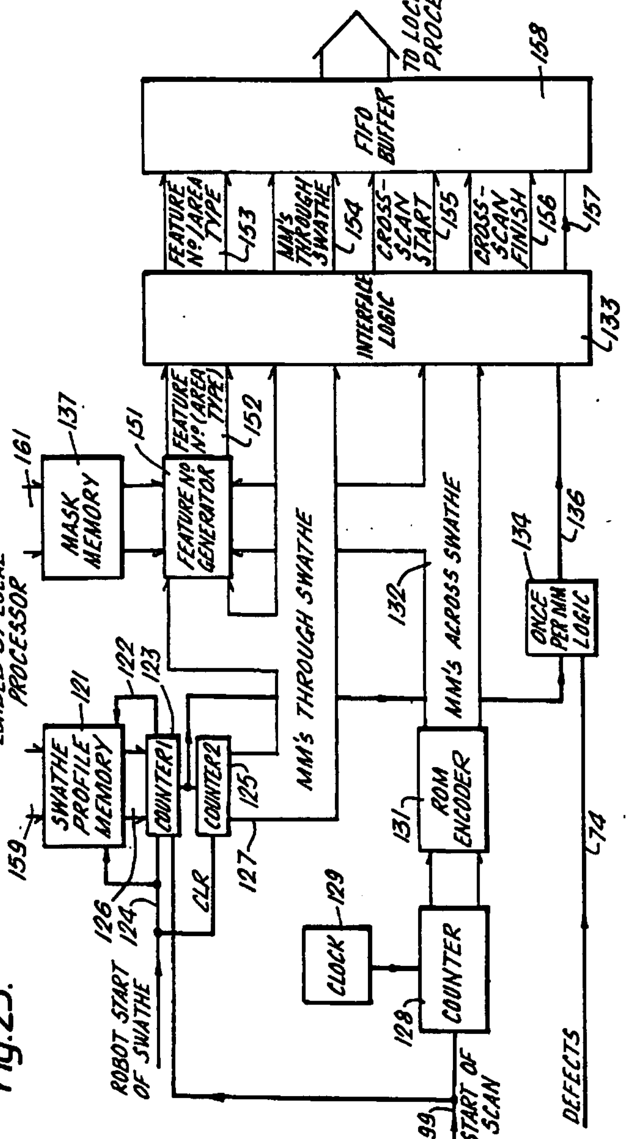


Fig.25.

13/23

Fig.26.

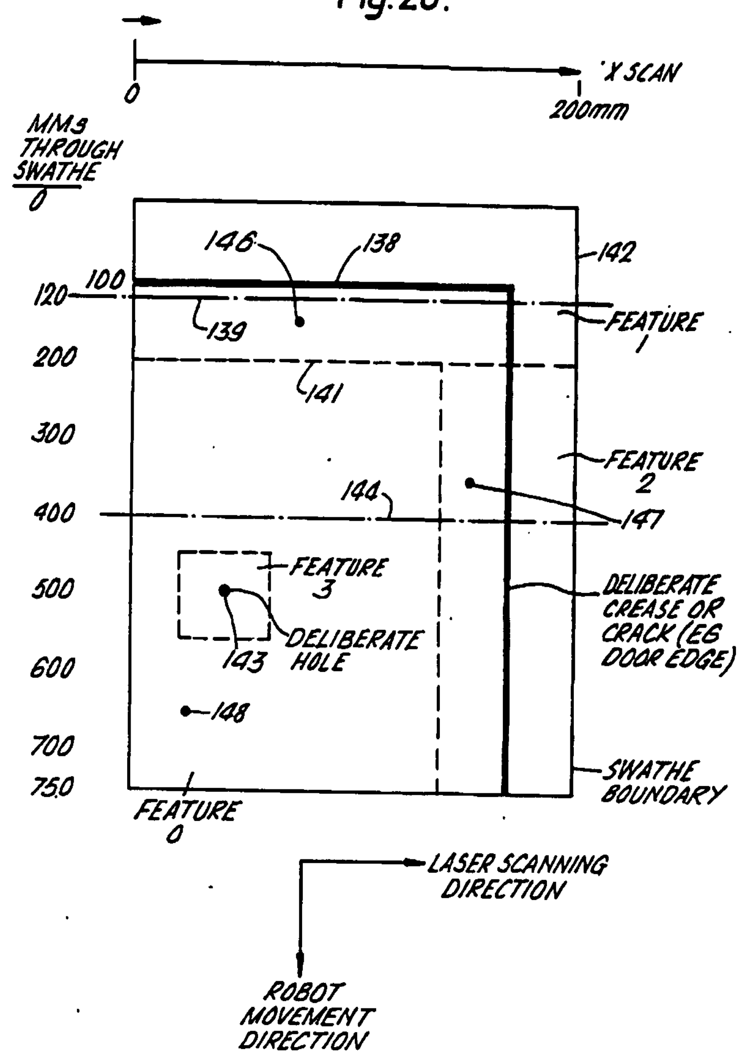
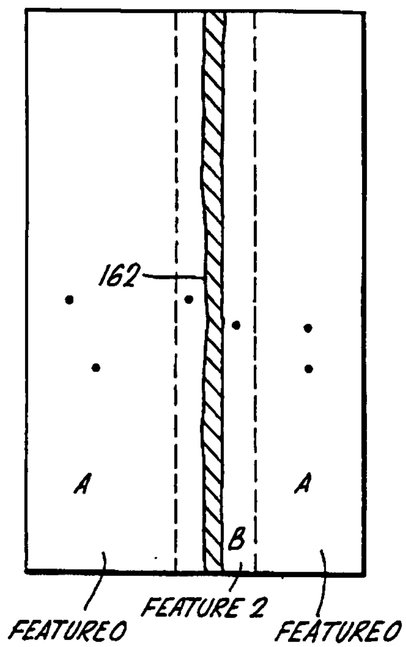


Fig. 27.



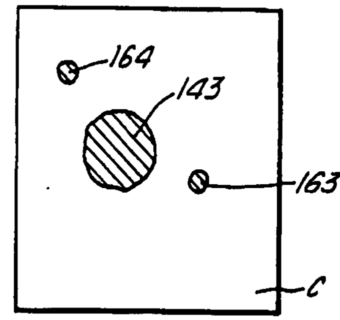


Fig. 28.

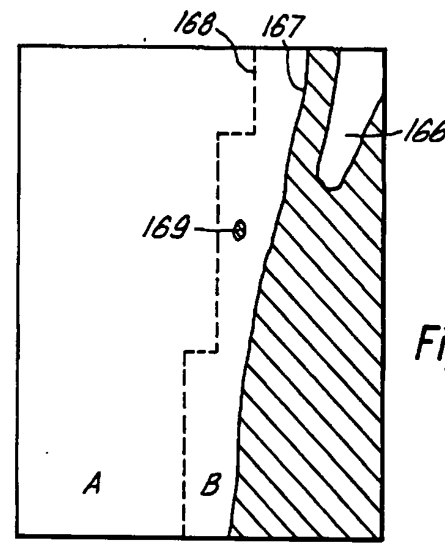


Fig. 29.

Fig.30.

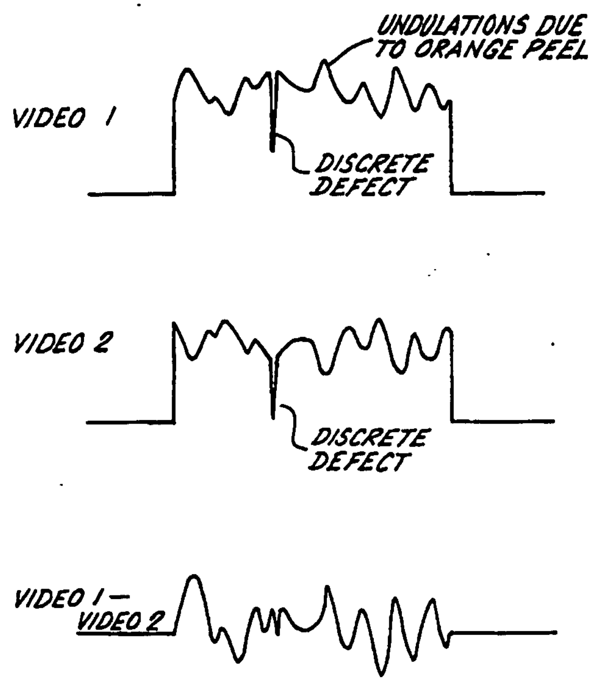

UNDULATIONS DUE TO ORANGE PEEL
VIDEO 1
DISCRETE DEFECT
VIDEO 2
DISCRETE DEFECT
VIDEO 1 — VIDEO 2

Fig.31.

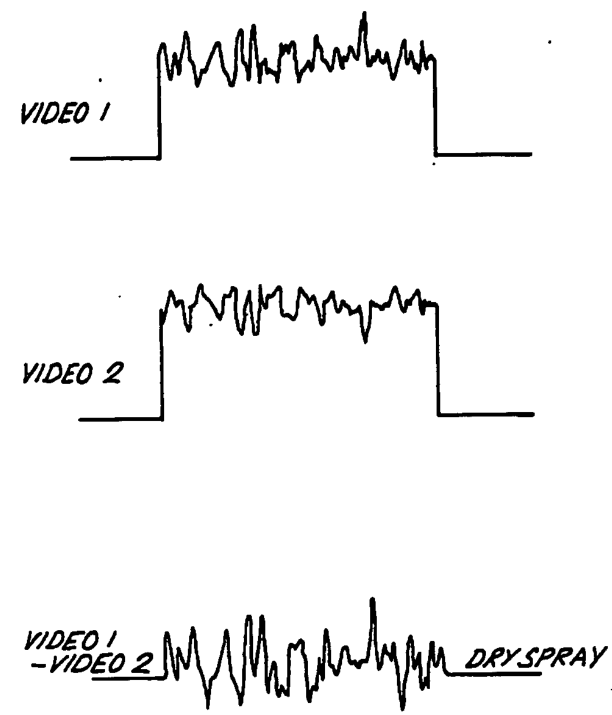

VIDEO 1
VIDEO 2
VIDEO 1 -VIDEO 2
DRY SPRAY

Fig.32.

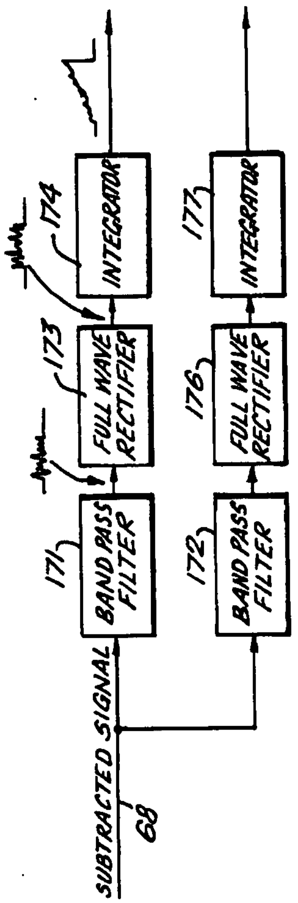
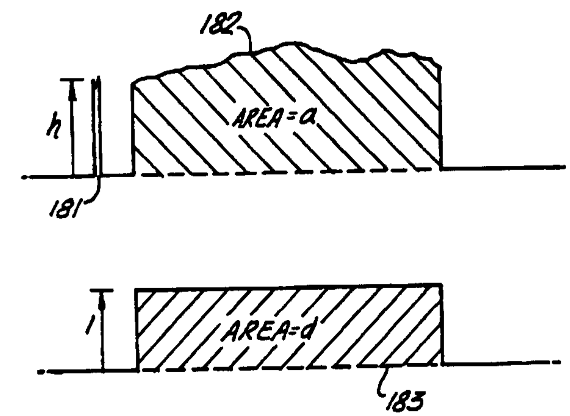

SUBTRACTED SIGNAL
68
171
BAND PASS FILTER
172
BAND PASS FILTER
173
FULL WAVE RECTIFIER
176
FULL WAVE RECTIFIER
174
INTEGRATOR
177
INTEGRATOR

Fig.33.


182
AREA=a
h
181
AREA=d
1
183

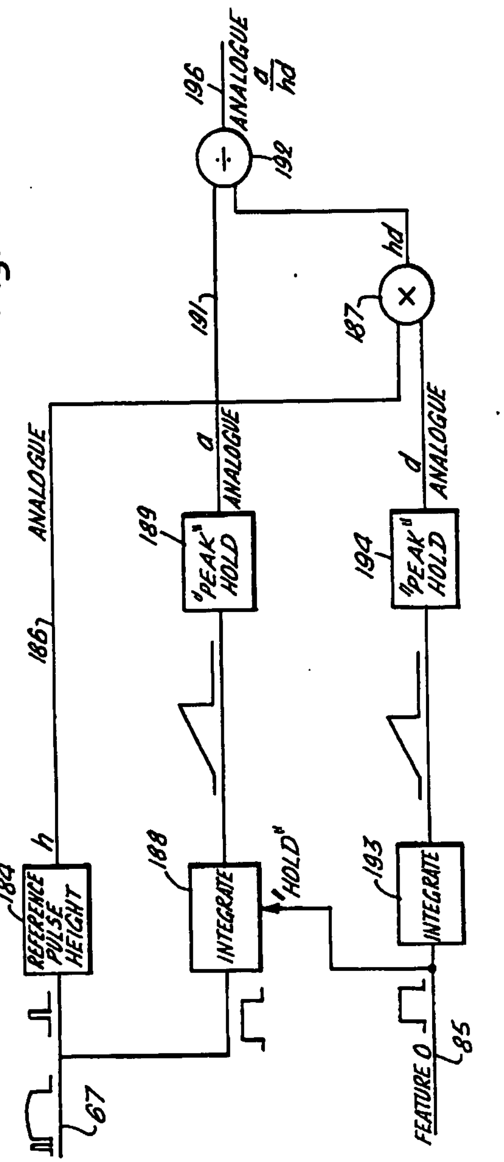


Fig.34.

SUBSTITUTE SHEET

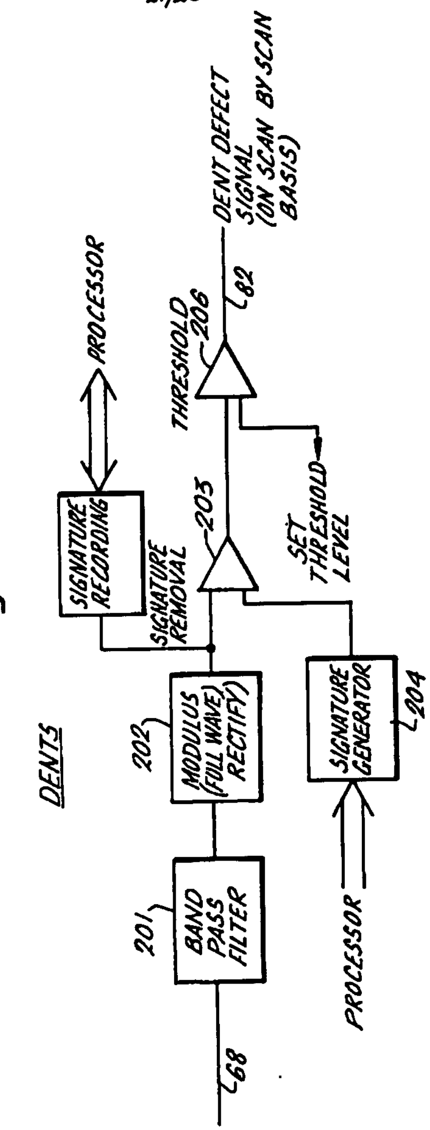


Fig.35.

SUBSTITUTE SHEET

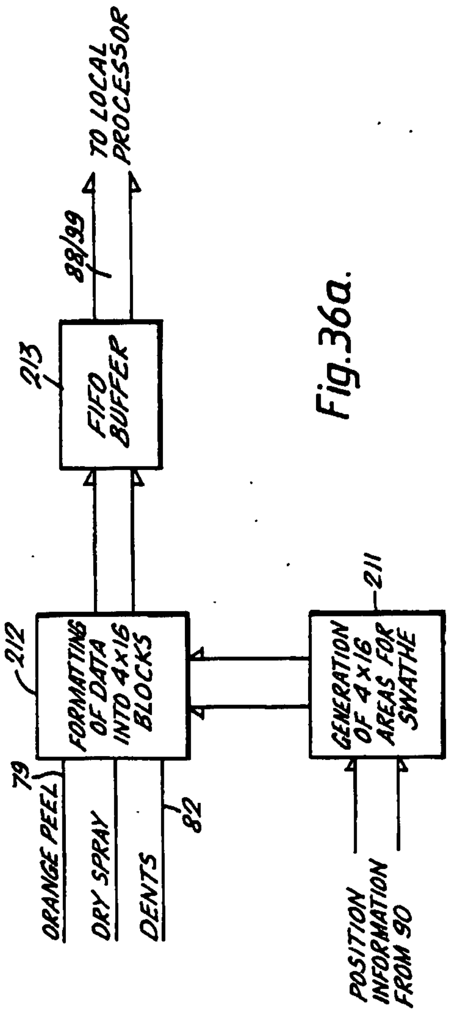


Fig.36a.

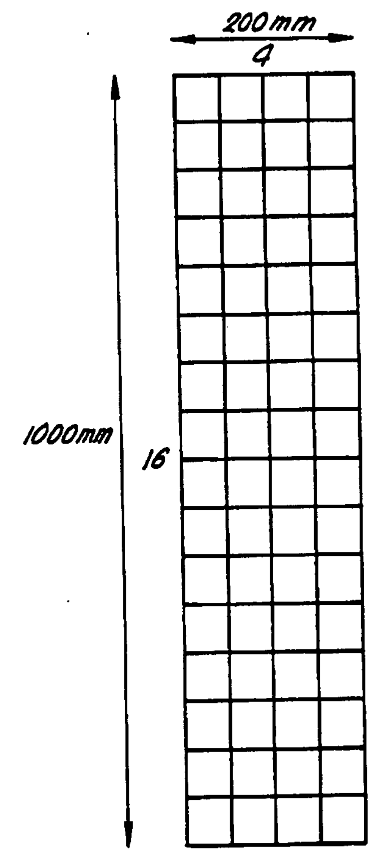


Fig.36b.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 86/00399

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 01 N 21/88

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	G 01 N 21/88 G 01 B 11/24 G 01 B 11/30

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	VDI Zeitschrift, volume 125, no. 21, November 1983, (Düsseldorf, DE), U. Breitmeier: "Einsatz opto-elektronischer Sensoren in der Fertigungsmesstechnik sowie zum Steuern von Robotern", pages 873-879 see pages 876-877, paragraph 5-5.1: "Fehlererkennung auf Werkstückoberflächen"	1,11
A	GB, A, 1390010 (SIRA INSTITUTE) 9 April 1975 see page 2, lines 14-51; page 3, lines 87-115	1,8-10
A	US, A, 3892494 (L. BAKER et al.) 1 July 1975 see column 5, lines 58-67; column 6, lines 1-13,45-61; column 10, lines 56-68	1
A	Patents Abstracts of Japan, volume 7, no. 150 (P-207)(1295), 30 June 1983, & JP, A, 5860241 (MITSUBISHI DENKI) (9 April 1983) see the whole abstract	1,3
A	US, A, 3918816 (G. FOSTER et al.) 11 November 1975 see column 3, lines 56-68; column 4, lines 1-32; column 6, lines 7-31; figure 2	1

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
15th October 1986	25 NOV 1986
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category [*]	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Transactions of the Institute of Measurement and Control, volume 5, no. 3, September 1983, (Dorking, GB), W. Hill: "Signal processing for automatic optical surface inspection of steel strip", pages 137-154 see page 148, paragraphs 8.1-8.2	14-17
P,X	WO, A, 85/03776 (DIFFRACTO LTD.) 29 August 1985 see page 12, lines 6-14; page 39, lines 4-14, 33-36; page 40, lines 1-7; page 48, claim 1; page 49, claims 7,8; page 50, claim 13; page 53, claims 25-27; page 54, claims 28-29; page 55, claims 32,36; page 56, claims 37-39; page 58, claims 46-47; page 59, claim 52; page 62, claims 64-65; figures 1,8-11	1-6,13
P,X	GB, A, 2159271 (NISSAN MOTOR CO.) 27 November 1985 see page 3, lines 63-90; page 6, lines 61-108; figures 7,12,19	1-3,5

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/GB 86/00399 (SA 13862)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 30/10/86

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 1390010	09/04/75	None	
US-A- 3892494	01/07/75	FR-A- 2193975	22/02/74
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		GB-A- 1403911	28/08/75
		JP-A- 49101082	25/09/74
US-A- 3918816	11/11/75	None	
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		JP-T- 61502009	11/09/86
GB-A- 2159271	27/11/85	JP-A- 60228910	14/11/85
		DE-A- 3515194	07/11/85
		JP-A- 60228909	14/11/85
		JP-A- 60228908	14/11/85

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